MEASURING THERMAL STRAINS DURING THE WELDING OF TUBES WITH DIC

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ABSTRACT: In this contribution the Digital Image Correlation (DIC) technique is used to observe the deformations that occur during the welding of a steel tube. The strains obtained with DIC are compared to electrical strain gauge (SG) measurements. The conclusion from this research is that the DIC technique is a valuable alternative for SG measurements.

1. INTRODUCTION

Residual stresses affect the use of steel tubes as a structural component, but already in the production of the component, during the laser cutting of the tube, the residual stresses influence the result. The gradual relief of the residual stress affects the precision of the cut. In order to predict the residual stress in the tube, a finite element (FE) simulation of the welding process is done. The results of these simulations have to be validated. Therefore the temperatures and deformations in the tube material are measured during the welding process. Electrical strain gauges (SG) are a common method to measure the deformations. This method has some drawbacks: the strain evolution during the process is only available in a certain direction at discrete positions and has to be compensated for the actual temperature of the SG (which is limited to about 120°C, implying measurement close to the weld is impossible). In the present research it is investigated to what extent it is possible to measure the deformations with the Digital Image Correlation (DIC) technique as this method does not suffer from the mentioned disadvantages, but at the other hand has the disadvantage that is commonly assumed not to be able to capture the typical small strains (<1000µm/m) in the welding process under consideration.

2. SETUP

2.1 Tube and welding process

The tube under consideration is a SS304 stainless steel tube with a diameter of 60mm and a wall thickness of 1.5mm. The tube is 400mm long, and a 300mm long weld is laid on top, parallel to the axis of the tube, see Fig. 1 (a). This is done with a TIG welding torch, held by a robot arm, ensuring a constant distance between the torch and the material and a constant welding speed of 2mm/s. The experiment was repeated for five tubes to check the reproducibility of the results.

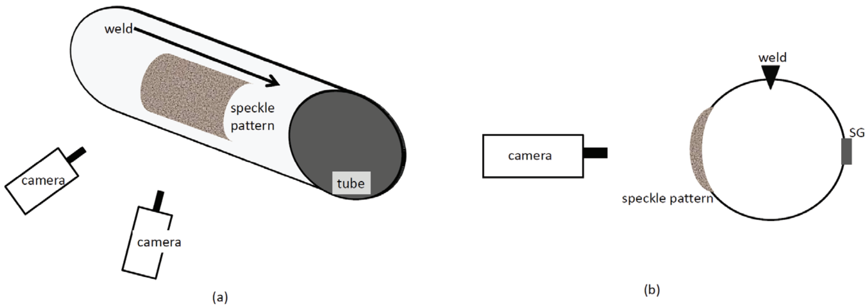

Figure 1 – sketch of the setup: (a) situation of the weld and speckle pattern on the tube; (b) position of the SG

2.2 Camera setup

As 3D deformations are measured on a 3D object, 2 cameras are set up in front of the tube. Distance between the tube and the cameras is 265mm. The images in this setup have a pixel/distance ratio of about 14px/mm. Images span over an area of 20 by 80mm. Special care was taken to shield the cameras from the blazing light of the weld beam. Markers (black crosses) were drawn in the speckle pattern for reference.

2.3 Electrical strain gauge (SG) installation

Two electrical strain gauges with a measuring grid of 3 by 6mm are placed on the tube at 90° position to the weld on the opposite side of the speckle pattern. The SG are compensated for a material with an expansion coefficient of 16µm/mK. As strains measured with SG are sensitive to the actual temperature of the material, the necessary temperature measurement near the SG was done with K-type thermocouples.

3. RESULTS

3.1 Processing DIC results

Images, taken every 0.5s during the welding step and every 1s in the cooling step of the experiment (2400 in total) were processed with our in-house DIC software MatchID. For the actual displacement calculation, a normalized-sum-of-squared-differences correlation algorithm with cubic B-spline interpolation is used. Next, the obtained displacements are smoothed via a so-called strain window method. The step size was taken as small as possible (2 to 5px) to maximize the amount of information, three values for the subset size were investigated: 13px (the smallest possible for the actual speckle pattern), 21px, and 55px. The SW was taken 5 by 5 and 15 by 15 subset centers.
As the measured strains are rather small compared to other DIC applications, a lot of noise is expected on the results. Indeed, as the strain development is observed for an individual center of strain window (SW) in the SG zone, the result is difficult to interpret: the variance on the strain result for a certain center of SW is large and the evolution of one center of SW may look totally different from the average over several SW. However, if the strain that is used to compare with the SG result is averaged over a region as large as the SG measuring grid, i.e. 3 by 6mm i.e. 40 by 80px, the noise on the resulting strain evolution is less than expected. The strain presented in Fig. 2 is averaged over such an area.

3.2 Processing SG results

The strains measured with the SG have to be corrected with the temperatures in the material near the strain gauge. It must be emphasized that it is impossible to measure the temperature exactly at the position of the SG and that the temperature correction has a major influence on the resulting strain curve of the SG, introducing errors in the SG measurement (the temperature at the SG position varies between 30°C and 75°C).

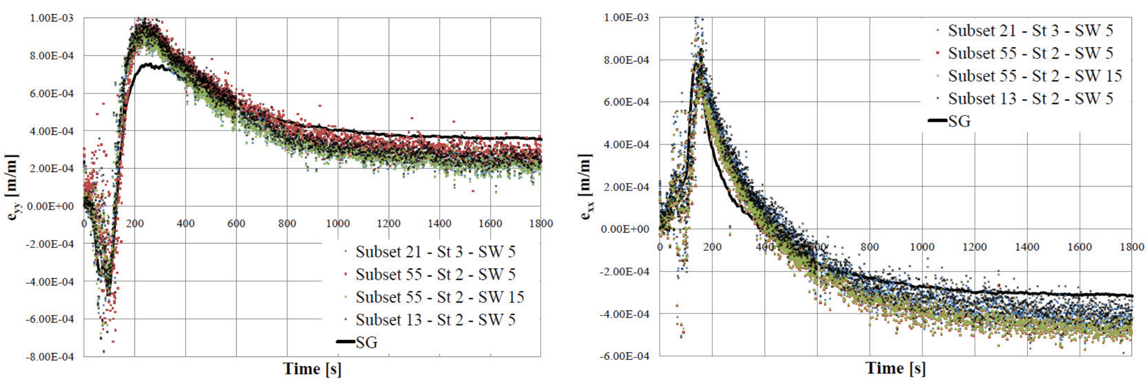

Figure 2 – Strain evolution during the welding as extracted with DIC (for different correlation settings) and with SG: e_{yy} in circumferential direction, e_{xx} in longitudinal direction

4. DISCUSSION

From Fig. 2 it is clear that when strains are averaged over a region as large as the SG surface, the correlation settings do not change the resulting strain evolution. The noise on the DIC measurement is less than expected: the evolution of the strain calculated with DIC is clearly the same as the SG measurement. The strain evolution as found with DIC is not exactly the same as the one from the SG but there is uncertainty in the SG results, due to the temperature compensation.

5. CONCLUSION

Strain gauge measurements and DIC measurements, both with their limitations yield similar evolutions of strain during the welding in comparable part of the tube. It seems that the DIC method can be trusted for this type of application, having the drawback that strains are to be averaged over a zone corresponding to that of a standard SG (which is rather large compared to other DIC applications), but having a number of advantages over strain gauges: strains are obtained over a certain surface (in the considered case about 1600mm²), strains are available at the surface of the tube in all directions, and there is no need for thermal compensation, which results in simpler setup and the possibility to measure the deformations closer to the weld. From these observations is concluded that DIC is well-suited to measure strains during the welding process and can be used as a validation technique for the strains predicted with FE simulations.